Grand Teton National Park

Geologic Resource Evaluation

Scoping Report

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Executive Summary

A Geologic Resource Evaluation scoping meeting for Grand Teton National Park took place on June 21, 2005, at park headquarters in Moose, Wyoming. The following day a geologic field trip highlighted glacial features of the park and of the Jackson Hole area. Scoping meeting participants identified the following geologic resource management issues as having highest priority.

1. Geologic hazard assessment and response particularly as related to earthquakes
2. Stream flow, stream channel morphology and dynamics
3. Glacial and climate change monitoring
4. Disturbed lands restoration

These and other geologic resource management topics are discussed in detail on pages 7 to 13.

Introduction

This report briefly describes the general geology of Grand Teton National Park (GRTE), including a geologic history of the park, geologic resource management issues in the park, and the status of Geologic Resource Evaluation (GRE) digital geologic mapping projects related to the park. Meeting participants identified the geologic management issues at a geologic scoping meeting held by the National Park Service Geologic Resources Division (GRD), GRE at park headquarters in Moose, Wyoming on Tuesday, June 21, 2005. The meeting was followed, on Wednesday, June 22, by a geologic field trip highlighting glacial features of the Jackson Hole area The purpose of the GRE scoping meeting was to discuss the status of geologic mapping in the park, the geologic bibliography, and geologic issues affecting Grand Teton National Park. Products derived from the scoping meeting are: (1) a digital geologic map of the park; (2) a geologic bibliography related to the park; (3) a scoping summary (this report), and (4) a GRE report which focuses in depth on the geologic resource management issues affecting the park and relates features and processes to geologic map units present in the park.

Grand Teton National Park was established by an act of Congress on February 26, 1929. At this time the park was 96,000 acres in size encompassing only the Teton Range and six glacial lakes at the base of the mountains. The need to protect a larger area as an ecosystem and to prevent unfettered development was recognized but delayed for many years by anti-park sentiment in the local community. Franklin D. Roosevelt established the 221,000- acre Jackson Hole National Monument by presidential proclamation in 1943. The monument was composed of Teton National Forest acreage, other federal properties including Jackson Lake, and a generous 35,000-acre donation by John D. Rockefeller, Jr. It was not until September 14, 1950, that the original 1929 park and the National Monument were united as Grand Teton National Park, creating the present-day boundaries encompassing about 310,000 acres (Skaggs 2000).

Geologic Setting

Grand Teton National Park is located in the Middle Rocky Mountain physiographic province that divides the Wyoming basin to the southeast and the Columbia River Plateau to the west (Figure 1). Much of the Middle Rocky Mountain province, including GRTE, is located within the intermountain seismic belt (ISB) an arc-shaped zone of earthquake activity that trends north-south through the intermountain west from northwestern Montana in the north, through Wyoming, Idaho, and Utah, and southern Nevada/northern Arizona to the south. The ISB separates the Rocky Mountains and the Colorado Plateau on the east from the Basin and Range province to the west. Tensional tectonic forces within the expanding Basin and Range province are responsible for creating the Teton, Wasatch, Hebgen Lake, and other major faults within the ISB (Smith and Siegel 2000). The Teton fault is an active normal fault that traces the eastern front of the Teton Range and is largely responsible for creating the modern Teton landscape. Most earthquakes in the ISB are shallow, occurring at depths less than 20 kilometers (12 miles). Fifty moderate-to-large (magnitude 5.5 to 7.5) earthquakes have occurred in this zone since 1900; the two largest were the 1959 Hebgen Lake, Montana earthquake (magnitude 7.5) and the 1983 Borah Peak, Idaho earthquake (magnitude 7.3) (http://www.seis.utah.edu/edservices/EES/ISB.shtml).

GRTE is essentially composed of two landforms; the Teton Range and Jackson Hole. On the western side of the Teton fault is the Teton Range a narrow, west-tilting, upthrown mountain block (horst) nearly 73 kilometers (45 miles) in length. Jackson Hole is the corresponding downdropped fault block (graben) east of the Teton fault. The Teton fault which separates these features has experienced several thousand magnitude 7 – 7.5 earthquakes over the past 13 million years. Today the highest peaks in the Teton Range rise nearly 2,134 meters (7,000 feet) above the valley floor. Scientists estimate that the floor of Jackson Hole has down dropped around 7,877 meters (16,000 feet) over the past 13 million years. The total amount of vertical offset along the Teton fault is difficult to calculate because rock eroded from the Teton Range and has been transported and deposited into the valley by streams and glaciers. Thus, the Tetons have been lowered and Jackson Hole has been filled with hundreds of meters of sediment obscuring the true offset. Using the best available data, scientists estimate that this total offset is near 7,010 meters (23,000 feet) (Smith and Siegel 2000). Seven of the spectacular peaks in this mountain range exceed 3.659 meters (12,000 feet) in elevation. Together these peaks form the Cathedral Group of which, Grand Teton is the highest peak, reaching an elevation of 4,197 meters (13,770 feet).

The Teton Range and Jackson Hole have both been dramatically sculpted by Pleistocene glaciation, specifically the Bull Lake and Pinedale glacial advances. During these glacial periods multiple glaciers flowed south from the Yellowstone Ice Sheet and converged in Jackson Hole. Ice up to 610 meters (2,000 feet) thick covered the valley floor. Alpine glaciers originating in the Tetons also formed during this time sculpting the peaks of the range. Glacial features in the GRTE area include: alpine glaciers, snow fields, cirques, U-shaped valleys, moraines, large glacial outwash planes, and glacial lakes.

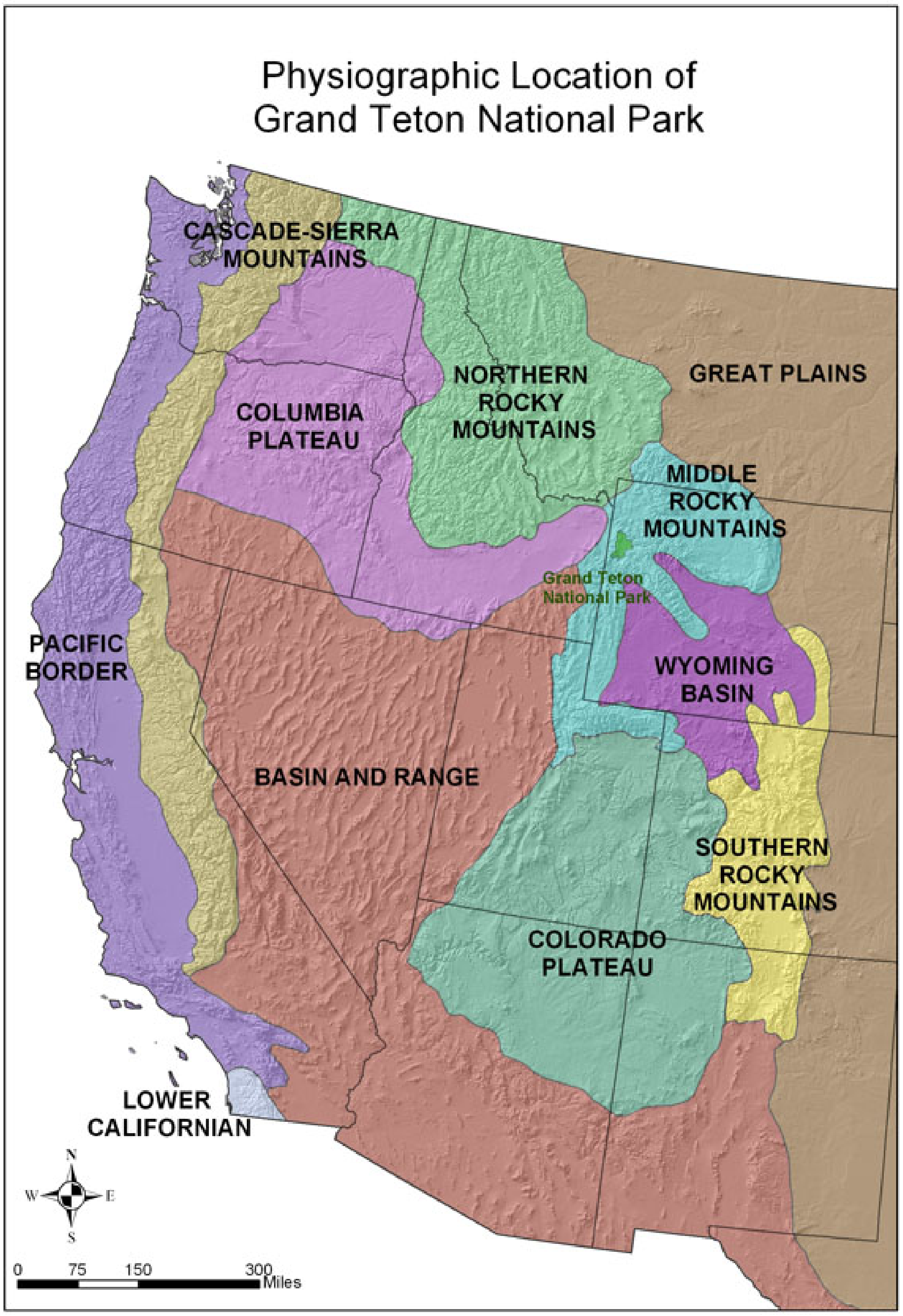


Figure 1: Physiographic location of Grand Teton National Park

Geologic History and Stratigraphy

Precambrian

The oldest rocks in the park are of Precambrian age, from about 2,680 Ma to about 765 Ma old. These rocks are part of the Wyoming craton, one of several tectonic plates that came together to form the Precambrian core of North America (Love et al. 2003). The oldest rocks are layered metamorphic gneisses, of Late Archean age. These rocks were originally sediments deposited in an ancient sea and later intruded by granitic volcanic rocks. The sediments were then metamorphosed during an episode of mountain building (orogeny. They are similar to the ancient rocks found on the Canadian Shield in southern Ontario, Canada, around the Great Lakes and Minnesota. During the metamorphic process, these rocks were intruded by gabbroic and granitic rocks. In the uppermost Archean, the metamorphic rocks were intruded by massive amounts of granite, including the Mount Owen Granite and several pegmatites. These pegmatite dikes are coarse-grained granitic rocks.

The last event, occurring in the Late Proterozoic, was the intrusion of diabase dikes of basaltic composition. The most prominent one is located on the east face of Mount Moran. These dikes that cut across the general metamorphic grain are nearly vertical sheets from a few centimeters to over 45.72 meters (150 feet) thick (Love et al. 2003). The Moran Dike has been dated at about 765 million years. Following metamorphism and uplift, the GRTE area was eroded eventually creating a relatively flat plain, probably similar to today's Canadian shield (Chronic 1984).

Paleozoic

At the beginning of the Paleozoic, the area of the future Grand Tetons began to subside and a shallow sea advanced from the west. Sedimentation into this basin resulted in the Flathead Sandstone and Gros Ventre Formation, both of Middle Cambrian age. The Flathead Sandstone consists of about 53.34 meters (175 feet) of brown, maroon, and white sandstone and green shale at the top.

As the sea continued to advance, the nearshore sands of the Flathead graded into muds that became the shales and limestones of the Gros Ventre Formation. The formation is divided into three members. From oldest to youngest they are: (1) Wolsey Shale Member, (2) Death Canyon Limestone Member, and (3) Park Shale Member (Love et al. 2003). These member reflect the advance and retreat of the shallow sea; limestone was deposited in the deeper water (> 30.5 meters or 100 feet), and shale in shallower water.

Sea level fluctuations continued throughout much of the Paleozoic with the deposition of the Gallatin Limestone (Late Cambrian, 54.86 meters (180 feet) thick), Bighorn Dolomite (Middle to Late Ordovician, 137.16 meters (450 feet) thick), the Darby Formation (Devonian, 106.68 meters (350 feet) of dolomite and shale), and the widespread Madison

Limestone (Mississippian, 335.28 meters (1100 feet) thick). There are large gaps in the stratigraphic rock record (no Lower Ordovician, Silurian, or Lower Devonian rocks) indicating periods of non-deposition or extensive erosion.

Toward the end of the Paleozoic, volcanic arcs developed to the west and the ancestral Rocky Mountains rose to the east in what is now central Wyoming. The Paleozoic shallow sea became increasingly restricted. Deposited in this restricted arm of the basin were, red sandstone (Amsden Formation) and light gray sandstone, dolomite and red shale (Tensleep Formation). Some of the material that contributed to these formations was derived from the Ancestral Rockies. The Permian Era is represented by the Phosphoria Formation which is 46-61 meters (150-200 feet) thick. The Phosporia is unusual in that it contains large deposits of calcium phosphate, which is commercially mined in Idaho.

Mesozoic

There are only very limited exposures of Mesozoic strata in the Tetons and these are outside of the park. Deposition in relatively shallow seas covering the GRTE area continued throughout the Mesozoic resulting in alternating beds of sandstone, shale, limestone, and dolomite. The aerial extent of the inland seas reached a maximum in the Cretaceous when the Great Cretaceous Seaway extended from the Arctic to the tropics covering the entire the west-central part of the North American continent.

There are 16 Mesozoic formations (including the Pinyon Formation, which is Upper Cretaceous-Lower Paleocene) identified in the Teton-Jackson Hole area with a combined thickness of over 3,048 meters (10,000 feet). Toward the end of the Cretaceous, the sedimentation became more rapid and there was a transition from marine sedimentation to more continental sedimentation. This type of sedimentation in the area includes conglomerate beds, which are mostly fluvial, coal beds, which indicate a marsh environment, and bentonite beds, which are derived from the alteration of volcanic ash (Tuttle et al. 2004).

The Targhee Uplift, to the northwest of the park, is part of the larger Laramide uplift that began in the Late Cretaceous and continued into the Tertiary. The Tarhee Uplift is shown today by a 30 foot bed of quartz conglomerate in the Upper Cretaceous Bacon Ridge Sandstone. Earlier in the Cretaceous, the Sevier Orogeny to the west (western Utah and Nevada) thrust layers of sediment compressing the rocks from the west to the east. To the east of the present day Tetons, the Laramide uplift formed the Rocky Mountains in Wyoming, Colorado, and New Mexico. These mountains are unique in that, rather than formed by shallow thrust sheets, they are upthrown blocks of sedimentary rock with cores of Precambrian metamorphic rocks and granites. This orogenic activity is reflected in the sedimentary record in the Teton and Jackson Hole area by large amounts of sediment, especially conglomerates, being eroded off these upthrown areas and deposited by predominantly fluvial processes. Also, during this time a large northwest-southeast trending uplift rose where the present Teton and Gros Ventre ranges are today. This probably extended up into the Yellowstone area (Love et al. 2003) uplifting the Precambrian rocks that today form much of the Teton Range.

Cenozoic

As Laramide uplift and thrusting continued, large quantities of sediment were shed off the highland areas and deposited in the Jackson Hole area. As the sediment accumulated in the basin, Jackson Hole subsided creating room for a thick sediment sequence. During the Eocene Epoch volcanoes erupted in the Absaroka volcanic field, north east of present day GRTE. These volcanic eruptions deposited huge volumes of volcanic ash that consolidated forming tuff, some of which is interbedded with conglomerate and sandstone containing fossilized leaves and petrified forests. Volcanic activity continued through the Oligocene and Miocene.

In the Pliocene faulting near the south boundary of the park resulted in the impoundment of Lake Teewinot. For the next 5 million years volcanic ash and other sediments collected in the lake with the rate of basin subsidence similar to the rate of sedimentation (Tuttle et al. 2004). About 9 million years ago, rhyolitic lava from the Yellowstone area flowed into the northern part of Teewinot Lake forming volcanic glass, or obsidian, from which, Native Americans made spears, arrowheads, and cutting tools. Volcanic activity continued into the Pleistocene. Significant movement on the Teton Fault began about 5 million years ago, with increasing activity into the Pleistocene. About 80% of the displacement was the dropping of Jackson Hole and about 20% attributable to uplift of the Tetons (Love et al. 2003).

Although there is some evidence attesting to several periods of glaciation, most of these glacial features were destroyed by subsequent glaciations. The more recent Bull Lake and Pinedale episodes are well preserved in the Jackson Hole area. Indeed, much of the landforms we see today are of glacial origin. The Bull Lake episode occurred 130,000 to 160,000 years ago and filled all of Jackson Hole with thick ice floes. Pinedale glaciation lasted from about 30,000 years ago to about 14,000 years ago. During the Pinedale, three lobes of ice moved into the Jackson Hole area: the Snake River lobe moved from north to south, the Pacific Creek lobe advanced to the southwest and the Buffalo Fork lobe moved to the west. Moraines, potholes, glacial lakes (including Jackson Lake), outwash fans, and gravel deposits remain as evidence of this glacial event.

Significant Geologic Resource Management Issues

The following issues were identified as significant geologic resource management issues at a GRE scoping meeting held at GRTE on June 21, 2005 and are presented generally in the order of priority discussed in the scoping meeting.

Earthquake Hazard Assessment and Planning

GRTE is located on the Teton fault, a major normal fault in the intermountain seismic belt (ISB). This fault has produced magnitude 7 – 7.5 earthquakes approximately every 2,000 years for the last 13 million years creating the area's two major landforms (the Teton Range and Jackson Hole). The GRTE area is currently situated in a "seismic gap," an area experiencing little or no seismic activity, although other areas of the ISB are still quite active. The Teton fault has not experienced any major earthquake activity for at least the last 4,840 years (Smith and Siegel 2000). This suggests that the Teton fault is significantly due for a major earthquake. Tectonic pressure on the fault is building and, though unpredictable, geologists are certain that this pressure will eventually be released in a major earthquake (Smith and Siegel 2000). Specific hazards associated with a major earthquake include: liquefaction, potential dam failure and flooding, building and bridge collapse, infrastructure damage, rock falls, landslides, and avalanches. All of these potential hazards would pose serious risks to the lives and safety of GRTE staff and visitors as well as residents of the Jackson Hole area.

Planning for earthquake hazard response is a high priority for GRTE. Scoping meeting attendees agree that a regional hazard response plan is necessary and should likely involve state and local governments, the National Guard, NPS, the Forest Service, the Bureau of Reclamation, and possibly the Fish and Wildlife Service. It may also be appropriate to approach the Federal Emergency Management Agency (FEMA) for ideas, suggestions, and perhaps leadership. A hazard response plan should include a review of possible scenarios, strategies for response, an inventory of available resources (human and other), and identification of responsibilities.

In order to better understand the geophysical processes at work in GRTE, a number of research and monitoring projects are taking place in the park. Twelve seismic monitoring stations are currently in place at GRTE as are several continuously recording GPS receivers. Research projects related to geophysical processes are also studying the historic return time of earthquakes on the Teton fault, investigating the ISB as a system, and synthesizing monitoring data in hopes of improving earthquake prediction.

Fluvial Geomorphology

Through the Jackson Hole area, the gradients of the Snake and Gros Ventre rivers, respectively, are about 3.6 and 7.2 meters per kilometer (19 and 38 feet per mile). Though some reaches of these rivers are considered braided, a multi-channel pattern is characteristic. True meandering patterns are only observed in stretches of these rivers where relatively low gradients and sediment levels coincide (Mott 1998).

The Snake River is generally slow moving and carries a low sediment load. However, tributaries of the Snake, which drain the mountains, move with high velocity even during times of low flow due to steep gradients. These tributaries carry high sediment load, particularly in the form of bedload, which is deposited at the point where they enter the Snake. This local sediment deposition would be cleared from the Snake River under natural flood conditions. However, the Jackson Lake Dam regulates the flow of the Snake River, limiting peak flow and removing the competence of the Snake to move these bedload deposits downstream. The horizontal stability of the Snake River decreases in segments influenced by the input of sediment from tributaries resulting in a more braided or meandering character developing along the Snake. In addition to altering the natural structure of the fluvial environment, critical for Snake River Cutthroat Trout spawning habitat, and riparian communities, the emplacement of large bedload deposits in the Snake is a management concern because these deposits block boat launch points to the river. With NPS approval, minor dredging is allowed in the immediate vicinity of launch areas in order to provide visitor access to the river in these areas (Mott 1998).

The high rate of aggradation and lateral migration found in many tributaries of the Snake River confound attempts to restrict the flow path of these streams to fixed bridge openings. Streams crossing alluvial fans are considered “chronically unstable” and are known to shift tens of meters in a single high flow event (Mott 1998). The migration of Spread Creek and Pilgrim Creek are of particular concern to park management. Spread Creek has the potential to threaten the Spread Creek Bridge and Teton Park Road, especially during times of peak flow. Redesigning or relocating the bridge may be the best option for avoiding future infrastructure failure. An engineering study of the fluvial geomorphology of the area should be undertaken prior to either of these efforts to ensure that new construction accounts for fluvial dynamics (Mott 1998).

Pilgrim Creek, as a result of engineering efforts, presently flows directly into Jackson Lake above the dam; but is migrating towards an eventual bypass of the dam and will flow directly into the Snake River below the dam. Pilgrim Creek migrated below the dam previously and was forced back into its present course by the construction of levees due to flooding in the town of Moran. However, the town of Moran no longer exists in a threatened location and flood concerns are currently managed using the Jackson Lake dam. Dam safety concerns have been raised as an argument for maintaining the Pacific Creek levee system, however, the Bureau of Reclamation, responsible for management of the Jackson Lake Dam, acknowledges that armoring the dam abutment is an alternative solution. The removal of the levee system and restoration of natural processes is encouraged because it is in keeping with the park purpose and NPS philosophy.

However, such restoration could lead to serious implications for park infrastructure and existing resource conditions as outlined in a 1998 NPS Water Resources Division Technical report (Mott 1998). These include:

- Potential compromise of the Teton Park Road could affect safety and transportation routes.
- Potential dissection of the willow flats area by an active stream channel would alter important moose habitat.
- Sediments brought in below the dam by Pilgrim Creek could partially fill in or destabilize the Oxbow Bend area.
- Spring Creek could capture Pilgrim Creek, reducing its value as a spawning area for cutthroat trout.

Mott (1998), notes that all of the above implications are natural processes that are likely to be accommodated by the ecosystem. In addition to Spread and Pilgrim Creeks, the Buffalo Fork Creek, Pacific Creek, and a number of others are quite active and could cause similar management concerns.

Glacial and Periglacial Monitoring

Twelve to fifteen alpine glaciers currently exist within Grand Teton National Park. Most of these glaciers are located high on the slopes of Mt. Moran. Several snow fields also exist within the park although recent history has shown that they are not permanent. Other glacial features include: rock glaciers, potential frozen ground beneath some talus slopes, and possible patterned ground freeze- thaw formations north of Leigh Canyon on the western side of the park.

Park staff observe that the glacial features of GRTE are diminishing each year. Glacial mass balance information is scientifically more revealing than glacial extent when evaluating the magnitude of glacial change. Mitch Plummer, of the Idaho National Lab, has the best and most recent mass balance data for many of the Teton glaciers. This data was obtained with funding through a Department of Energy project on climate change. However, Kelly Elder and Ed Williams, of Brigham Young University- Idaho, are currently keeping track of most glacial monitoring projects in Grand Teton National Park. Glaciers are sensitive indicators of regional climate change and shifting annual precipitation patterns. Monitoring changes in the composition and extent of Teton glaciers may yield important information to scientists studying climate change and global atmospheric circulation patterns. Regional tectonics and the migration of the North American plate over the Yellowstone Hotspot may also be related to glacial change in GRTE. Potential methods of monitoring changes to the glacial features include: mass balance analysis, aerial photography, and radar or lidar surveying.

In addition to the long-term scientific goal of understanding regional climate change in the Tetons, glacial monitoring has some immediate safety issues. Technical climbers come from around the world to practice their sport in the Grand Tetons. Changing glacial conditions can destabilize formerly safe routes endangering climbers who may not appreciate the dynamic nature of these features. It is important for GRTE to educate climbers about the active glacial features in the park and make an effort to provide up to date information on backcountry conditions.

Glacial meltwater contributes to GRTE groundwater supplies and probably feeds several high alpine lakes. A current research project indicates that increasing levels of nitrates in high alpine lakes are possibly linked to increasing amounts of glacial meltwater (S. O'Ney pers. comm. 2005).

Cave and Karst Resources

The central Tetons are composed almost completely of insoluble Precambrian rock thus they do not contain caves or karstic features. The northern and southern extents of the Teton Range however are covered by thick sedimentary deposits where cave and karst features are known to exist. The geologic formations containing caves are the Madison Limestone, the Death Canyon limestone member of the Gros Ventre Formation, and the Bighorn Dolomite. The southern limestone area lies primarily outside the park boundary in the Targhee National Forest. Well-known caves in that area include the Fossil Mountain Ice Cave and Wind Cave as well as Wyoming's deepest cave: the Rendezvous Peak Cave. The limestone area north of the central Tetons is included in the GRTE boundary and the adjoining John D. Rockefeller Jr. Memorial Parkway (Plantz 1978).

Caves occur in three areas in GRTE: (1) The Death Canyon – Spearhead karst area in the southern portion of the park, (2) The Wall area in the northern portion of the park, and (3) The Moose Basin Divide area in the northern portion of the park. All three of these locations are accessible to backpackers and horseback riders (Plantz 1978). Seventeen separate caves are documented within the GRTE and the adjoining John D. Rockefeller Jr. Memorial Parkway (R. Kerbo, pers. comm. 2005). Most of these caves are small and "do not appear to need any management" (Plantz 1978). According to Plantz (1978) only the Hole-In-The-Wall Cave receives significant traffic and is in need of management. This cave is especially significant because of the locally rare mineral speleothems found there. In addition to the more commonly found dripstone formations (such as flowstone, stalactites, and stalagmites) globulites, helictites, and some ice speleothems are found in this cave. Damage to speleothems is evident and is a continuing concern as the cave is easily accessible by visitors from the abandoned Old Skyline trail (Plantz 1978).

In addition to cave resources, karst topography and karst hydrology exist in the northern and southern parts of GRTE. Awareness of karstic groundwater flow patterns and potential areas where sinkholes could form is important for developing sound and responsible infrastructure.

Geothermal Features

Geothermal features, primarily in the form of hot springs, are present in and around GRTE. Love et al. (2003) listed 11 known hot springs in the Jackson Hole area. Temperatures in these springs range from 64 ºF – 162 ºF. Only Huckleberry Hot springs, located south of Yellowstone National Park in the John D. Rockafeller Memorial Parkway, is identified as having high levels of radioactivity. Geothermal features of GRTE are being surveyed as part of the Inventory and Monitoring Program in the Greater Yellowstone Network.

Wetlands

Wetlands, marshes, and swamps are all present in GRTE. These areas are concentrated along the Snake River, its tributaries, and near several alpine lakes. GRTE wetlands are supported by streams, springs, or seeps, and provide vital habitat for a wide variety of plants and animals. Oxbow Bend and Willow Flats are well-known wetland areas that provide excellent habitat for moose. In addition to providing habitat for plants and animals, wetlands can serve an important ecological role by naturally filtering pollutants from the hydrologic system and providing flood control buffers.

Oil and Gas Development

Although there are no current oil and gas activities or leases in the park, it is important for park staff to be aware of potential development outside park boundaries, which could impact the park. The potential for oil and gas development in the Bridger-Teton National Forest adjacent to the park is high. Some oil and gas activity is currently taking place just northeast of the park boundary on US Forest Service lands. There are four management areas of the Bridger-Teton National Forest: the Hoback, Moccasin, Wind River, and Green River basins. Of these only the Hoback basin management area drains directly to the Snake River and the confluence is several kilometers downstream from the park boundary. However, the remaining three management areas lie immediately east of the Snake River drainage, abutting the drainage divide. Because there is an extensive amount of carbonate strata in the drainage divide (Nolan and Miller 1995, Mott 1998), karst hydrology, and known inter-basin transfer of groundwater (Huntoon and Mills 1987), there is a significant concern that contaminants generated by well drilling and oil and gas production could be carried through the karst groundwater network to park tributaries (Mott 1998).

Sand and Gravel

GRTE contains numerous paved and unpaved roads that the NPS maintains in cooperation with the Federal Highway Administration, the State of Wyoming, and other agencies. Maintenance of these roads requires aggregate materials. There is an abundance of road aggregate within the park and a shortage of external commercial sources within reasonable hauling distance of the central eastern and northern park areas (NPS 1986). NPS policy prohibits new borrow pit creation in parks. It further stipulates that present borrow pits not be further used unless it is totally impractical to import materials. Presently 38 borrow pits, from which at least 100 cubic yards of material have been excavated, exist within the park. The pits range in size from 0.1 to nearly 40 acres (NPS 1986). The NPS has been involved in restoration efforts to reclaim some of the sand and gravel pits previously used for park road maintenance because of sedimentation impacts to wetlands. In 1986, 40,000 cubic yards of material were excavated from the Gros Ventre River channel upstream from the Highway 89 bridge on National Elk Refuge lands. Future aggregate needs may be satisfied by utilizing materials from the Spread Creek drainage on US Forest Service lands adjacent to the park (Mott 1998). No wetland impacts are anticipated as a result of this aggregate mining. GRTE anticipates a continued need for aggregate resources for park maintenance and may also be interested in reclaiming some of the historic gravel mining pits located on park lands.

Historic Mining

Jackson Hole and GRTE have a relatively minor mining history. Gold prospectors canvassed the area in the mid- to late- 1800's with minimal success. Most gold prospectors engaged in placer mining, which left little lasting impact on the landscape. Today the only evidence of gold mining are a few abandoned mining structures, some pits, and ditches used in placer mining. Miners realized more success with talc and coal extraction in the Jackson Hole area. Subbituminous coal of Cretaceous age underlies a large portion of Jackson Hole. Coal was excavated from an area near the Jackson Lake Dam during dam construction and from a mine on Black Tail Butte. Native Americans were the first to mine talc from the Jackson Hole area. Significant archaeological sites associated with these early mines may exist in the area. Talc deposits contain small pods of ultramafic material commonly known as "teton jade". Mica, garnets, and "Teton jade" found in GRTE are all tempting to mineral collectors. Accessible areas known to contain these minerals should be monitored to the extent possible to protect these resources. Most of the abandoned mines in the park are not considered a danger to park visitors. However, the Webb Canyon addit, part of an abandoned talc mine north of Webb Canyon, should be evaluated for closure as it may pose a potential risk to visitor safety.

Mass Wasting

Mass wasting in the form of rockfall, landslides, and avalanches pose serious hazards in many areas of GRTE. Earthquakes and heavy rainfall are the most probable triggers that could cause large landslide or rockfall events. Digital landslide hazard maps identifying the locations most vulnerable to landslides have been created by the Wyoming Geological Survey and should be consulted prior to new infrastructure development.

Climbing

GRTE has a rich climbing and mountaineering history dating back to the mid- 1800's. This climbing history is a major resource for the park, which attracts numerous visitors each year. The use of appropriate tools and hardware along climbing routes is an issue of intense debate in the climbing community. Many climbing experts believe that the presence of permanent hardware along climbing routes compromises the integrity of rock and therefore can pose a potential risk to climbing safety or make historic climbing routes unsafe. No mechanized drilling for hardware installation is currently allowed in the park.

GRTE needs to establish clear guidance on this topic with particular attention to visitor safety and preservation of historic climbing routes.

Paleontology

A comprehensive paleontological survey of GRTE was completed during the summer of 2002. This survey included 13 separate fossil bearing units exposed within the park, an extensive literature search, and an inventory of GRTE museum collections. Over 160 types of fossils are identified by this survey; the majority of these are Mississippian and Pennsylvanian age Brachiopods and Gastropods (Tracy 2003). Fossils are non-renewable natural resources that provide significant research value for reconstructing paleo-environments and understanding geologic history. These resources are in need of protection. Tracy (2003) identifies five areas of GRTE where paleontological resources are at high risk in the park because of fossil abundance and ease of access. These areas are: 1) Black Tail Butte, 2) Berry Creek Trail, 3) Rendezvous Mountain, 4) near Fossil Mountain, and 5) Granite Canyon Trail (Tracy 2003). In addition to macro fossils identified by the Tracy (2003) survey, microfossils such as diatoms and fossil pollen grains are found in the park and are of interest to scientists studying regional climate change.

Bentonitic Soils

Bentonitic soils are rich in bentonite, a clay that swells when wet, causing the ground surface to heave and buckle. Any structures, roads, trails, facilities, etc. located on bentonitic soils will be negatively impacted. Such soils are known to exist in limited areas of the park. Bentonitic soils have been identified near the park boundary in the Toby Pass area as well as in isolated clay lenses near Ditch Creek and Lost Creek. A corner of the Jackson Lake Lodge built on the Teewinot Formation has been affected by the shrink and swell of bentonite rich soils. Identifying areas with clay soils is especially important for future infrastructure development.

Geologic Mapping Status

Grand Teton National Park and the Inventory and Monitoring program identified 36 7.5' quadrangles of interest to park natural resource management (see page 15). The park boundary extends into 19 of these quadrangles. The USGS has compiled and extended a number of 1:24,000 scale 7.5' quad maps creating a 1:62,500 map covering the entire park and part of the surrounding area. The compiled map is:

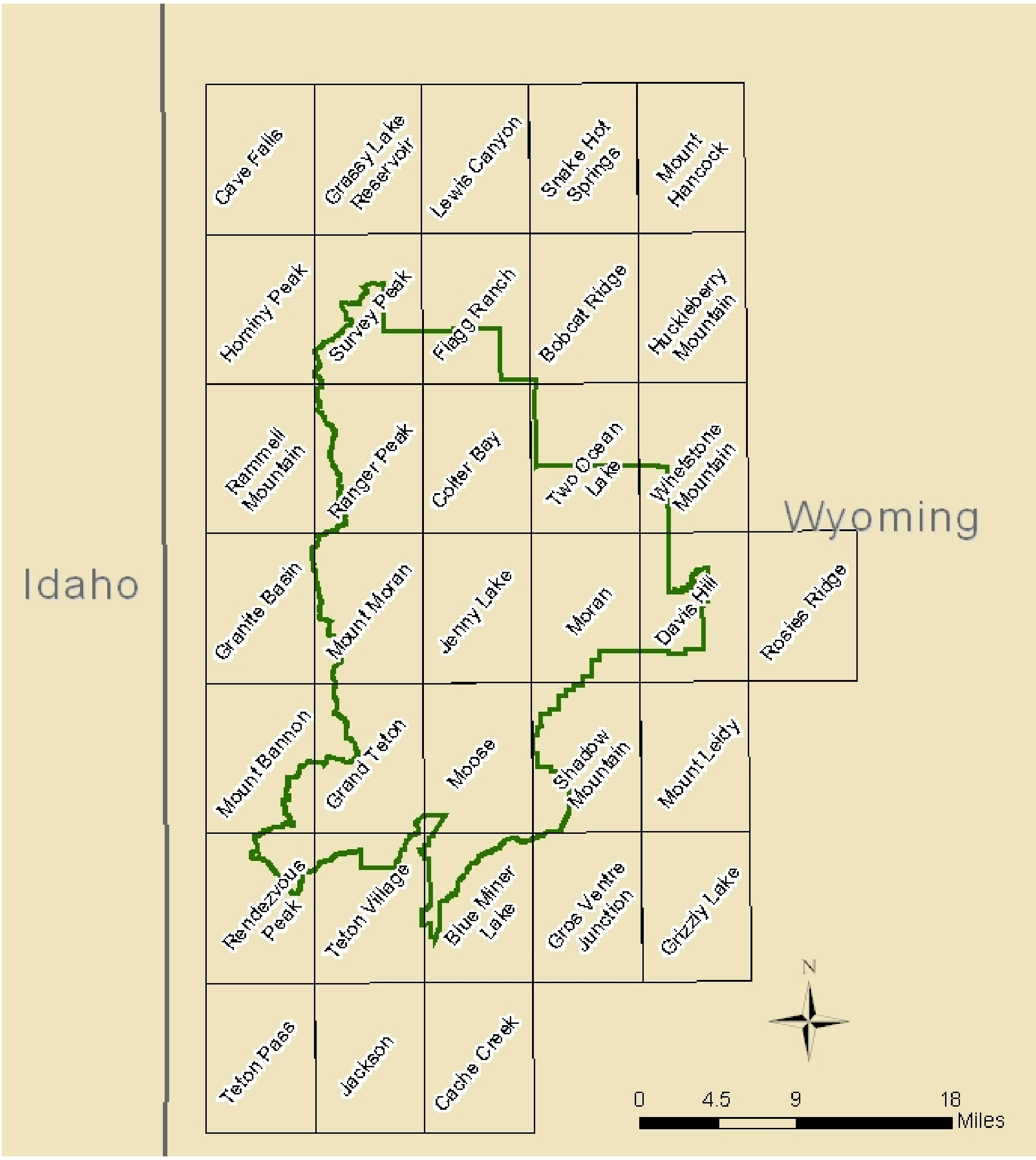
Love, J.D., J.C. Reed, and A.C. Christiansen. 1992. *Geologic map of Grand Teton National Park*. Teton County, Wyoming: USGS. I-2031. 1:62500 scale. (Gmap ID - 1168)

This map has been digitized by NPS-GRE staff and the digital data is available for download online from the NPS Natural Resource Data-store (http://science.nature.nps.gov/nrdata/). The following geologic features derived from the source map are provided in both coverage and shapefile format for use in a GIS:

- Area glacial features
- Attitude observation units
- Linear dike features
- Area dike swarms
- Fold axes/hinge lines
- Faults
- Area geologic units
- Area geologic unit information table
- Linear geologic units
- Area hazard features
- Linear hazard features
- Hazard point features
- Paleo-shorelines
- Map source(s) table
- Mine related features
- Linear glacial moraine features

A small graphic of the digital map is included on page 19 of this report. Because interpretation of Jackson Hole's glacial features has changed significantly in the past several years, a series of surficial geologic maps produced by Dr. Ken Pierce of the US Geological Survey will be completed and digitized with GRE assistance in the near future. These maps, in combination with the completed digital geologic map, will provide a foundation for sound geologic understanding and resource management in Grand Teton National Park.

GRTE Quadrangles of Interest



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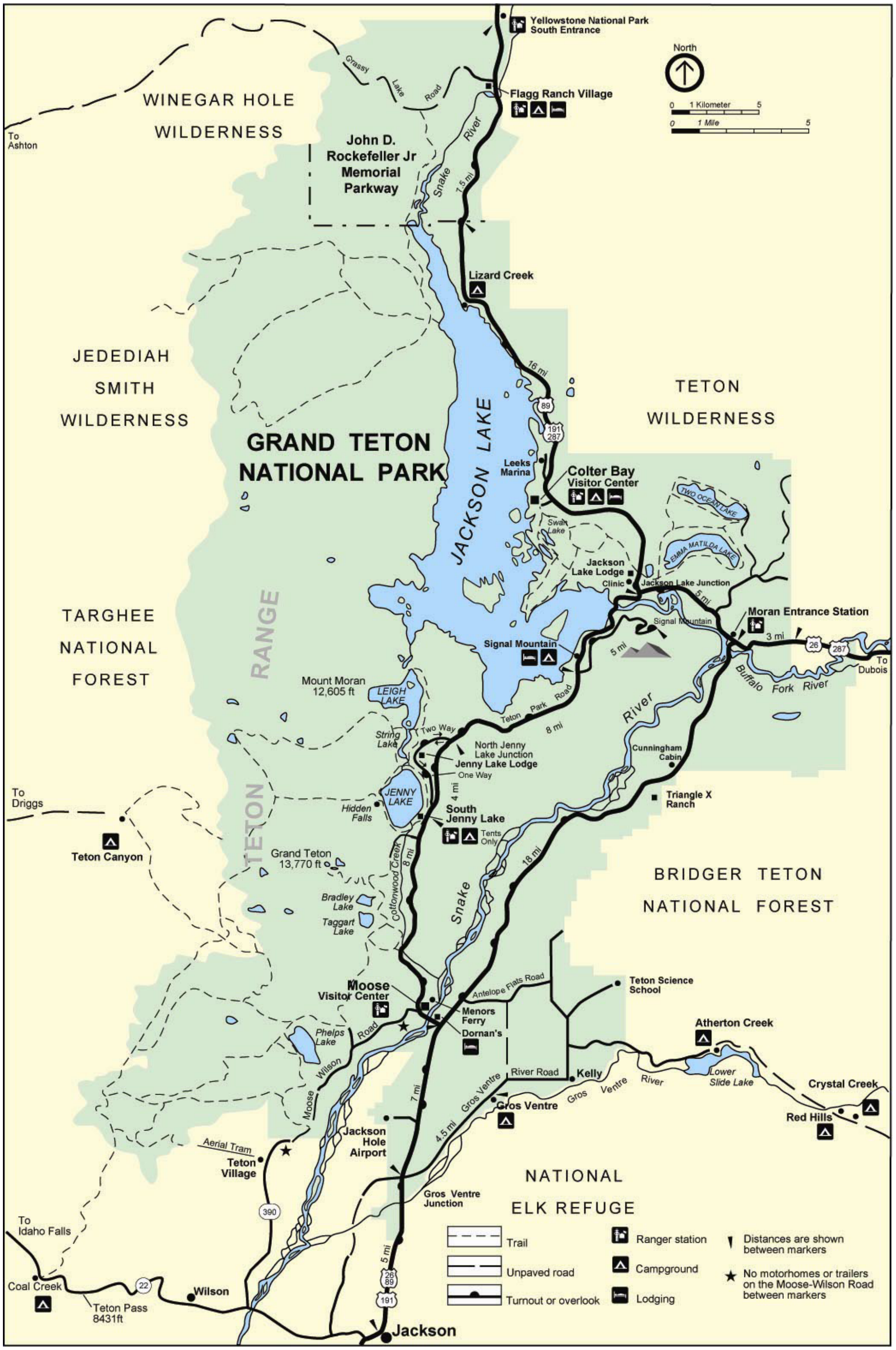
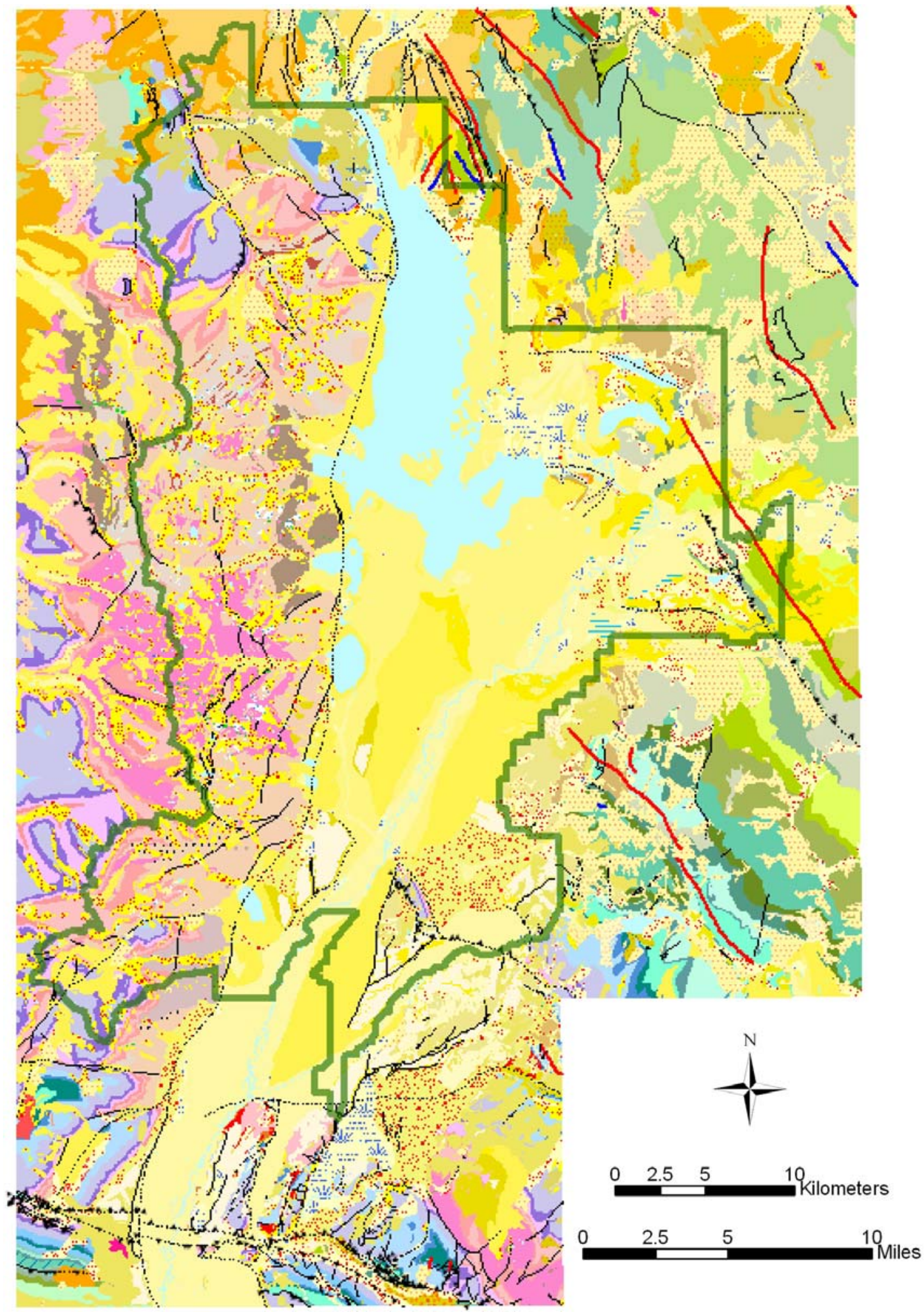
Area Map



Yellowstone National Park South Entrance
North
Flagg Ranch Village
WINEGAR HOLE WILDERNESS
John D. Rockefeller Jr Memorial Parkway
To Ashton
Lizard Creek
JEDEDIAH SMITH WILDERNESS
GRAND TETON NATIONAL PARK
JACKSON LAKE
TETON WILDERNESS
Leeks Marina
Colter Bay Visitor Center
Jackson Lake Lodge
Jackson Lake Junction
Moran Entrance Station
Signal Mountain
TARGHEE NATIONAL FOREST
TETON RANGE
Mount Moran 12,605 ft
LEIGH LAKE
String Lake
North Jenny Lake Junction
Jenny Lake Lodge
JENNY LAKE
South Jenny Lake
Hidden Falls
To Driggs
Teton Canyon
Grand Teton 13,770 ft
Cunningham Cabin
Triangle X Ranch
BRIDGER TETON NATIONAL FOREST
Bradley Lake
Taggart Lake
Moose Visitor Center
Menors Ferry
Dornan's
Teton Science School
Atherton Creek
Phelps Lake
Kelly
Lower Slide Lake
Crystal Creek
Gros Ventre
Red Hills
Jackson Hole Airport
Teton Village
Aerial Tram
NATIONAL ELK REFUGE
Gros Ventre Junction
To Idaho Falls
Coal Creek
Wilson
Teton Pass 8431ft
Jackson
To Dubois
Trail
Unpaved road
Turnout or overlook
Ranger station
Campground
Lodging
Distances are shown between markers
No motorhomes or trailers on the Moose-Wilson Road between markers

Geologic Map Graphic



Legend

- Grand Teton NP
- thrust fault
- thrust fault, approximated
- thrust fault, concealed
- normal fault
- normal fault, approximated
- normal fault, concealed
- probable Holocene fault
- anticline
- anticline, approximated
- syncline
- syncline, approximated
- Qa - alluvium, gravel, and sand; and flood plain deposits
- Qs - swamp deposits
- Qla - lacustrine and related deposits
- Qtr - travertine
- Qc - colluvium
- Qf - alluvial-fan deposits
- Qt - talus and related deposits
- Qls - landslide debris
- Qls1 - landslide debris, unit 1
- Qls2 - landslide debris, unit 2
- Qls3 - landslide debris, unit 3
- Qlg - landslide and glacial debris, intermixed or undivided
- Ql - loess
- Qlb - loess and boulders
- Qly - Leidy Formation
- Qg4 - glaciation 4 - drift
- Qg4j - glaciation 4 - Jackson Lake moraine
- Qg4b - glaciation 4 - Burned Ridge moraine
- Qo4j - glaciation 4 - outwash gravel (JL)
- Qo4b - glaciation 4 - outwash gravel (BR)
- Qtg - terrace gravel
- Qg3 - glaciation 3 - drift
- Qo3 - glaciation 3 - outwash gravel
- Qg2 - glaciation 2 - drift and outwash deposits
- Qlab - Lava Creek Tuff, member B (Yellowstone Group)
- Qlc - Lewis Canyon Rhyolite
- QTs - clay, silt, sand, conglomerate, till, and (or) loess
- QTc - conglomerate
- QTgd - glacial drift
- Tab - andesite and basalt
- Tr - rhyolite
- To - obsidian pipes
- Td - dacite flows
- Tcgn - conglomerate containing no volcanic material
- Ta - andesite
- Tp - perlite
- Tfp - felsite porphyry
- Ts - scoria
- Tbxp - flow breccia and pumice
- Tbxs - pumice breccia and sandstone
- Tdi - intrusive dacite
- Tbxc - flow breccia and conglomerate
- Tm - mafic dike
- Tb - basalt
- Ttrp - trachyte porphyry
- Th - Huckleberry Ridge Tuff
- Thc - Huckleberry Ridge Tuff, Member C
- Thb - Huckleberry Ridge Tuff, Member B
- Tha - Huckleberry Ridge Tuff, Member A
- Tg1 - drift(?) probably related to glaciation 1
- Tsi - Shooting Iron Formation
- Tcc - Conant Creek Tuff
- Tcg - conglomerate
- Tte - Teewinot Formation
- Ttem - detachment mass of Madison L. within Teewinot
- Tc - Colter Formation
- Tbc - basalt intruded into Coulter Formation
- Twr - White River Formation
- Twi - Wiggins Formation
- Thp - Hominy Peak Formation
- Tbb - basalt breccia
- Tl - Langford Formation
- TKp - Pinyon Conglomerate
- Kh - Harebell Formation
- Kme - Meeteetse Formation
- Kmv - Mesaverde Formation
- Ks - Sohare Formation
- Kb - Bacon Ridge Sandstone
- Ksb - Sohare Formation and Bacon Ridge Sandstone
- Kc - Cody Shale
- Kf - Frontier Formation
- Ka - Aspen Shale
- Kmt - Mowry and Thermopolis Shales
- Kbr - Bear River Group
- Kg - Gannett Group
- KJc - Cloverly Formation and Morrison(?) Formation
- Jsg - Sundance Gypsum Spring Formations
- Jsp - Stump Formation and Preuss Redbeds
- Jt - Twin Creek Limestone
- JTRn - Nugget Sandstone
- TRc - Chugwater Formation
- TRa - Ankareh Shale
- TRt - Thaynes Formation
- TRw - Woodside Formation
- TRd - Dinwoody Formation
- Pp - Phosphoria Formation
- PPNMwa - Wells and Amsden Formations
- PNMta - Tensleep Sandstone and Amsden Formation
- Mm - Madison Limestone
- MDmd - Madison Limestone and Darby Formation
- Dd - Darby Formation
- Ob - Bighorn Dolomite
- Cg - Galltin Limestone
- Cgg - Gallatin Limestone and Park Shale Member of GV
- Cgv - Gros Ventre (GV) Formation
- Cgd - GV Formation, Death Canyon Limestone M.
- Cgf - Wolsey Shale M. of the GV Formation and Flathead Sandstone
- Cf - Flathead Sandstone
- PCq - quartz veins
- PCd - diabase dikes
- Xmo - Mount Owen Quartz Monzonite and associated pegmatite
- Xg - granitic rocks of the Gros Ventre Range
- Wr - Rendezvous Metagabbro
- Wu - ultramafic rocks
- Wa - amphibolite
- Wgm - layered gneiss and migmatite
- Wi - magnetite iron-formation
- Woo - biotite gneiss with magnetite eyes
- Wom - gneiss with pods and lenses of metagabbro
- Ww - Webb Canyon Gneiss
- Wag - augen gneiss
- water
- ice
- shear zone